28 Multi-stage yield and quality improvement of hemp fibres for clothing applications - prerequisite for revival of hemp cultivation

Authors

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Keywords
Hemp, retting, textiles, local production, fibres

Abstract

Fabrics consisting of natural or man-made fibres of cellulosic origin are widely used in clothing, for their comfort-related properties amongst others. Despite its huge ecological footprint, more specifically high water and pesticide consumption during cultivation, cotton is still the most used natural fibre in the textile industry. Lately interest in hemp cultivation is becoming more prevalent in many industrialized countries as a consequence of its environmentally friendly cultivation, sustainable processing and versatile applications of the entire hemp plant. Hemp fibres are nowadays mainly used for the pulp and paper industry, building, technical textiles, animal bedding, pellets, etc. Lack of knowledge during cultivation, pre-processing and the spinning of long fibres, as well as inconsistent fibre quality are the main reasons that impede the use of hemp fibres for high-quality clothing applications.

The choice of the hemp variety, and sowing and harvesting conditions seem to be decisive during hemp cultivation, and the retting process is responsible for a great deal of fibre yield and quality. These approaches are investigated by the research project 'Own grown hemp' aiming at a revival of the hemp industry in Flanders, and which specifically investigates how the quality of hemp fibre can be controlled at several stages in the value chain. This paper presents selected results of the project relating to the relationship between fiber quality and yield, genotype and retting method. Five hemp cultivars (USO 31, Dacia Secuieni, Bialobrzeskie, Futura 75, Carmagnola Selezionata CS) and two types of retting (field or dew retting and enzymatic field retting with Texazym SER-7 conc.) are discussed.

In this study, genotype proved to be relevant for determining the fibre yield and quality of hemp. Although dry matter yields tended to be higher in the late flowering genotypes (Bialobrzeskie and CS) because they reached a bigger plant height at full flowering (237 cm and 279 cm respectively), bast fibre content was highest (38%) in the early flowering genotype (USO 31). The method of retting not only slightly affected the colour but also the fineness and strength of the hemp fibres and the differences were

significant depending on cultivar. The results seem also to recommend enzymatic field retting as a better alternative to field retting in terms of fiber tenacity.

Introduction

Fabrics consisting of natural or man-made fibres of cellulosic origin are widely used in clothing for their comfort-related properties among others. Despite its huge ecological footprint, specifically high water and pesticide consumption during cultivation, cotton is still the most used natural fibre in the textile industry. For instance, production of one pair of cotton jeans requires about 10.000 litres of water on average (Cherret et al., 2005) and about 325g pesticides (Renaerts et al., 2009). Using five to ten times less water and no pesticides during cultivation, hemp fibres could be a promising alternative to cotton.

Hemp fibres were used for centuries for sails and ship ropes until the beginning of the 20th century, when it was prohibited in Europe due to negative association with marijuana. Since the 1990s cultivation of hemp cultivars with tetrahydrocannabinol (THC) $< 0.2\%$ is allowed in Europe, and interest in hemp cultivation is increasing in many industrialized countries as a consequence of its environmentally friendly cultivation, sustainable processing and versatile applications of the entire hemp plant (Cherret et al., 2005). In Europe, the area is increasing every year mainly in the cooperative context - particularly in France (more than 15.000 ha, EIHA, 2017) and also in Belgium, (around 500 ha in 2017). However, the revival of hemp is still slowed down by the fact that no homogeneous fibre quality can be guaranteed (due to the variable, natural retting) and because, so far, the focus has been on relatively low-grade bulk applications (bedding, building blocks, insulation and sheet materials and bio-energy). In addition, a large proportion of the specialized processors who are able to develop high-quality fibre and textile applications with fine hemp yarns (linen) have disappeared after the deterioration of flax and hemp use, or they no longer have the appropriate equipment. Methods and machines that are developed for flax processing offer possibilities for application in hemp cultivation and processing, but probably require specific adjustments.

The influence of hemp cultivation factors on fibre yield and quality have not been properly addressed so far. The choice of the hemp variety, sowing and harvesting conditions seem to be decisive factors during hemp farming. Few studies have compared the performance of the current commercial genotypes of industrial hemp (Aubin et al., 2016; Tang et al., 2016; Campiglia et al., 2017) and limited information is available on the fibre quality of hemp cultivars. Since the fibre quality depends on the hemp variety, and sowing and harvesting conditions, wide variations in the values of the breaking tenacity of the fibres are obtained (Sankari, 2000).

The retting - and to some extent also harvesting - is a first hinge step between the downstream (cultivation) and midstream (extraction of the fibres) segments in the chain, as it affects the fibre yield and the basic qualities (length, thickness, strength, colour, composition) of the raw bast fibres, and thereby the quantity of marketable fibres, their intrinsic quality and suitability for further processing. Harvesting takes place at the time of the desired maturity (in the flowering stage in order to obtain both high fibre yield and optimal quality for textile applications) of the plants and usually in a dry period; retting then requires sufficient moisture and suitable temperatures for microorganisms to do their work (pectin degradation). For flax, dew retting in the field is still the most common method which also appears to be applicable for hemp. In the past, retting was also done in watercourses (the Lys, 'the Golden River') and in heated basins ('water retting'). In good climatic conditions, the yield and intrinsic qualities of the raw bast fibres in the harvested hemp straw will be high. However, the results may be suboptimal by 'under retting', or strongly degraded by 'over retting' on the field. In worst cases, the harvest is completely lost due to adverse climatic conditions (Liu et al., 2015). In order to gain more control over yield and quality after harvesting, a determination of the optimal harvest time and, above all, a control of the pectin and lignin degradation is necessary. Within the classical approach (dew retting) this can be done by a regulation of the moisture content and the biochemical degradation processes in the straw on the field ('enzymatic dew retting'). Few studies exist that investigate enzymatic field retting of hemp (Marek et al., 2008) and a limited number of enzymes suitable for spraying on the field are commercially available (i.e. Texazym SER-7). It is claimed that Texazym SER-7 spray is able to increase long fibre yields by more than 40% (Marek et al., 2008 and Antonov et al., 2007).

The overall aim of the project 'Own grown hemp' is to support the revival of the hemp industry in Flanders, especially for high-quality textile applications. Therefore this project investigates how the quality of hemp fibre can be controlled at several levels of the value chain. The specific objectives are: (1) to locally evaluate the adaptation and production potential of commercial hemp cultivars and (2) to gain more control of the retting process through enzymatic activation on the field or in (industrial) plants. This paper deals with a field experiment followed by field (dew) retting and enzymatic field retting of five hemp cultivars, and presents the first results regarding the quality (i.e. colour, tenacity and finesse) and yield of hemp fibres.

Methodology

Field experiment

A field experiment was carried out at the University College Ghent experimental farm located in Bottelare (Flanders, Belgium). Five different hemp cultivars (i.e., USO 31, Dacia Secuieni, Bialobrzeskie, Futura 75, Carmagnola Selezionata CS) from different origin and maturity were sown in a randomized complete block design with four replicates. Single plot size was 45 m^2. Plant density was estimated at 240 plants m^{-2} and nitrogen fertilization was 108 kg N ha^{-1}. Crop development was monitored by measuring seedling emergence, flowering, plant density, plant height, stem diameter. Plants were harvested at initiation of flowering and each plot was divided in three fractions at harvest. One part of the straw stayed on the field for classical field (or dew) retting. A second part of the straw stayed on the field for enzymatic field retting by spraying enzymes (i.e., Texazym SER-7 conc) on the straw on the field. A third part was harvested 'green' and used for tests of pure enzymatic retting in lab-scale reactors, by using different commercially available enzymes. Yields were determined by measuring straw weight (fresh and dry weight). Plant samples were oven dried at 70°

C until constant weight in order to evaluate the above ground biomass. Dry matter content was calculated as the ratio of dry weight/fresh weight. For determination of the fiber content, dried hemp stems were broken using lab-scale flax processing equipment. Statistical analyses were performed to assess the effect of cultivar on yield components using Statistical Package for the Social Sciences (SPSS statistics 22.0).

Fiber extraction

During the primary processing of hemp, the shives are mechanically separated from the fibers. The retted hemp stalks are processed to long fibers on a flax scutching line. The focus is on obtaining long, intact fibers. The steps are: breaking the woody core, hackle, remove the shives, and finally scutching, whereby the fibers become parallel. The released short fibers can still be separated from the shives on a short fiber line. The scutching ribbon is offered to the spinners for further processing into a yarn. For the considered five cultivars, fibers were mechanically extracted from straw that underwent dew (field) retting and enzymatic field retting, as discussed above. Fibre yield and fibre quality of the different genotypes was determined.

Colour testing

Colour has always been an important factor of raw fibres for textile production. The D1925 yellowness index system was developed to give a better system to quantify the yellowness of wool fibres. The colour of the retted fibres was measured with a Datacolor Spectraflash SF550. Each sample (16 per cultivar) was measured 4 times and moved during the measurement and rotated 90°. The spectrophotometer has a measuring hole of 30mm and used the light source D65 / 10°. The CIE tristimulus values for X, Y, Z were determined by the Datacolor Software. Afterwards, the Yellowness Index D1925 can be calculated from these values (ASTM method D1925). On the basis of these colour measurements, the colour differences can be determined by the different retting methods and genotypes.

Tensile strength and fineness

The strength of hemp fiber is important and should be adequate to allow further (mechanical) textile processing. Hemp is known as a strong fibre, but the different retting processes can have an influence on the fibre strength. Fibre strength was determined for each variety and retting method used, according to ISO 5079 (1995). The atmosphere for preconditioning, conditioning and testing was the standard atmosphere as specified in ISO 139 (2005). The fibre bundles, chosen at random, were measured with the Instron tensile tester, model 2519-105 using a gauge length of 50 mm between the 2 clamping points, a pretension value of 0,05 N (rate 3 mm / min) and tested at a constant rate of 5 mm / min until break. Fiber tenacity (cN/tex) is expressed as ratio of fiber tensile strength (cN) to its linear density (tex). Linear density (tex) is determined as ratio of fiber mass (grams) to length (1000 m).

Results and discussion

Biomass yield

Significant differences between the five cultivars were found for plant height at full flowering, dry matter yield, bast content and bast yield (Table 1). The average plant height at full flowering ranged from 154.5 cm (USO 31) to 278.9 cm (Carmagnola

Selezionata, CS). Stem dry matter yield at full flowering ranged from 5,79 Mg ha^{-1} (USO 31) to 14,02 Mg ha^{-1} (Bialobrzeskie). As a consequence of its short vegetative phase, the early-flowering cultivar USO 31 produced the lowest biomass yield. Bast fibre content ranged from 25 % (CS) to 38 % (USO 31) at full flowering, depending on the cultivar. Bast yield depended on both stem yield and bast fibre content in the stem and ranged from 2,20 Mg ha^{-1} (USO 31) to 4,77 Mg ha^{-1} (Bialobrzeskie). Cultivar Bialobrzeskie had the highest stem yield and a medium bast fibre content at full flowering; consequently it had the highest bast fibre yield. Yield and fibre content in this field experiment are comparable to numbers reported in previous studies (Tang et al., 2016; Campiglia et al., 2017). A significant positive correlation was found for dry matter yield and plant height (R^2=0,549) and for dry matter yield and bast yield (R^2=0,771). A significant negative correlation was found for plant height and bast content (R^2=0,765).

Table 1 - Yield components of different cultivars at full flowering

Cultivar	**Plant height at harvest (cm)**	**Dry matter yield (Mg ha^{-1})**	**Bast content (%)**	**Bast yield (Mg ha^{-1})**
USO 31	154,5 c	5,79 c	38 %	2,20 c
Dacia Secuieni	238,9 b	10,14 b	33 %	3,31 b
Bialobrzeskie	236,9 b	14,02 a	34 %	4,77 a
Futura 75	240,8 b	10,02 b	29 %	2,88 b
Carmagnola Selezionata (CS)	278,9 a	11,59 b	25 %	2,90 b

Numbers followed by different letters in the same row are statistically different for P < 0.05 (Tukey test).

Enzymatic field retting (EFR) with Texazym SER-7 conc. did only give an increase in long fibre yield with the cultivars USO 31 (approx. 7 %) and Carmagnola Selezionata (approx. 33 %) (Table2). The result obtained with Carmagnola Selezionata approaches the results of the field experiment described by Marek et al., 2008.

Table 2 - Long fibre Yield of different cultivars after field retting (FR) and enzymatic field retting (EFR) with Texazym SER-7conc.

Cultivar	**Field retting**		**Enzymatic field retting**	
	% long fibers	Ton / ha	% long fibers	Ton / ha
USO 31	15	0,50 d	16	0,54 b
Dacia Secuieni	11	1,09 b	8	0,79 b
Bialobrzeskie	19	1,47 a	17	1,35 a
Futura 75	10	0,88 bc	6	0,64 b
Carmagnola Selezionata	6	0,69 cd	8	0,86 ab

Numbers followed by different letters in the same row are statistically different for P < 0.05 (Tukey test).

Colour

The whiteness of the fibres is expressed with the yellowness index YI D1925: the higher the index the lighter the colour. Large colour differences could be visually observed within a plot (single plot size of the randomized complete block design was 45 m^2). A number of 16 colour measurements were carried out per variety / retting method. The CIE Tristimulus values and average and standard deviation of D1925 Yellowness Index values of the different cultivars after field retting and enzymatic field retting are given in Table 3.

Table 3 - CIE Tristimulus values (X, Y, Z) and D1925 Yellowness Index values of different cultivars after field retting (FR) and enzymatic field retting (EFR) with Texazym SER-7conc.

Cultivar	**X**	**Y**	**Z**	**YI D1925**
USO 31 FR	26,88	27,06	20,36	47,31 ±4,03
USO 31 EFR	23,92	24,22	16,64	54,22 ±5,47
Dacia Secuieni FR	25,72	25,77	20,42	42,44 ±5,17
Dacia Secuieni EFR	23,52	23,65	19,4	38,97 ±4,33

Bialobrzeskie FR	27,01	27,08	21,05	44,88 ±5,66
Bialobrzeskie EFR	26,19	26,22	20,15	45,95 ±5,16
Futura 75 FR	23,12	23,2	18,77	41,25 ±3,76
Futura 75 EFR	23,48	23,62	19,14	40,91 ±5,24
Carmagnola Selezionata FR	22,64	22,83	18,22	42,04 ±4,12
Carmagnola Selezionata EFR	23,25	23,43	18,84	41,46 ±2,94

Figure 1 gives the D1925 Yellowness Index values and the standard deviation of the different cultivars after field retting and enzymatic field retting with Texazym SER-7conc. A significant difference ($p<0.05$) was noticed between the D1925 Yellowness Index value of different cultivars regardless the retting method. Among these five cultivars there is only a significant difference between field retting and enzymatic field retting for cultivars USO 31 ($p<0.001$) and Dacia Secuieni ($p<0.05$).

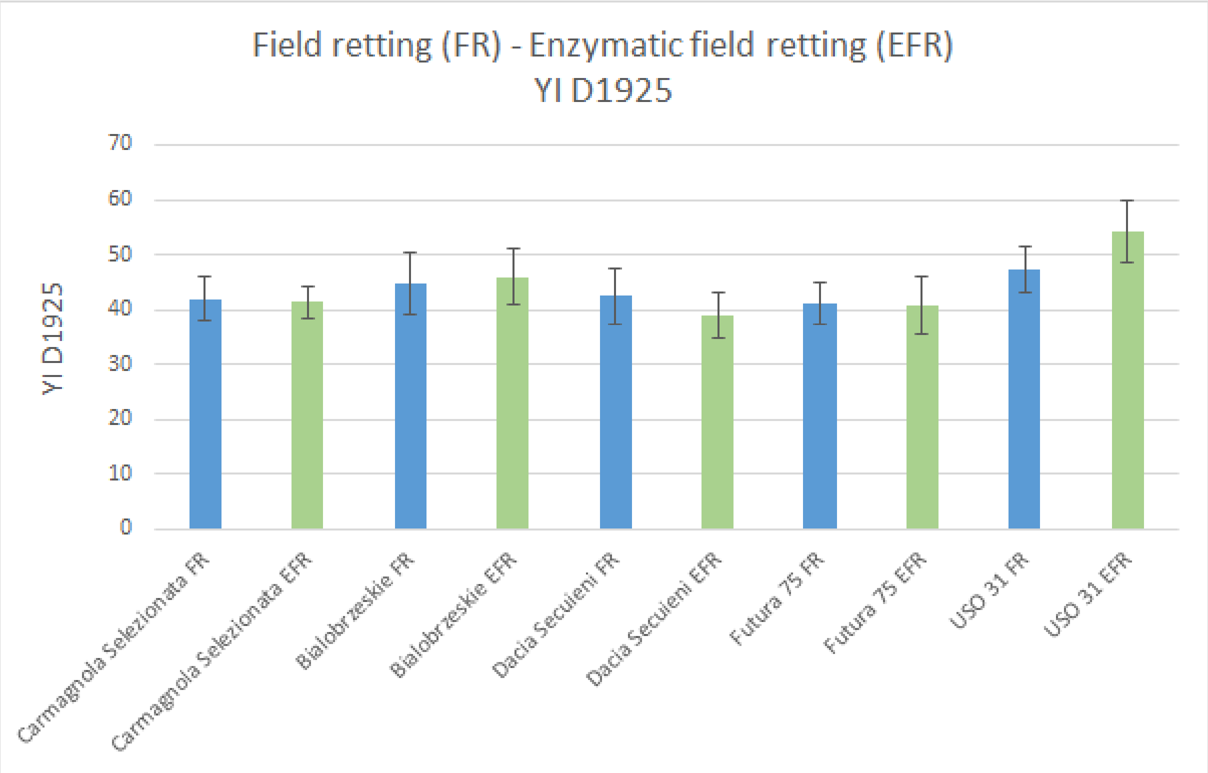

Fig. 1 - D1925 Yellowness Index values of different cultivars after field retting and enzymatic field retting

Tensile strength

To examine the effect of the enzymes that were sprayed on the field during the field retting, the linear density and the tensile strength of the obtained long fibres was determined for the cultivars Futura 75, Carmagnola Selezionata and Dacia Secuieni. For this, 150 measurements were performed per quality (cultivar) and per retting method (field retting (FR) and enzymatic field retting (EFR)). The average length, mass, breaking force, linear density and tensile strength per tested cultivar are given in Table 4. Only for cultivar Dacia Secuieni there is a significant difference ($p<0.05$) in tex between field retting and enzymatic field retting. This difference was mainly determined by the fibre length that was much shorter in field retting than in enzymatic field retting.

Table 4 - Linear density (tex) and fibre tenacity (cN/tex) of hemp fibres after field retting and enzymatic field retting

Cultivar	**Fibre length (mm)**	**Fibre mass (mg)**	**Breaking load (N)**	**Fibre linear density[a] (tex)**	**Fibre tenacity[b] (cN / tex)**
Dacia FR	117,6 ±27,3	1,31 ±0,39	2,41 ±1,38	11,72	20,77
Dacia EFR	153,0 ±44,7	1,00 ±0,41	1,57 ±1,14	6,73	26,34
Futura FR	157,0 ±47,9	1,01 ±0,43	1,51 ±0,96	6,69	23,91
Futura EFR	164,9 ±52,9	1,13 ±0,41	1,73 ±1,31	7,18	24,60
CS FR	178,6 ±53,2	1,03 ±0,39	1,91 ±1,24	5,98	31,73
CS EFR	174,6 ±51,5	0,99 ±0,43	2,06 ±1,31	5,71	36,10

a-tex is expressed as ratio of fiber mass (g) to length (1000 m); b- tenacity is expressed ratio of load required to break the fiber (cN) to linear density of the specimen (tex)

In Figure 2 the fibre tenacity of Futura 75, Carmagnola Selezionata (CS) and Dacia Secuieni after field retting (FR) and enzymatic field retting (EFR) is shown. Between the different cultivars there is a significant difference ($p<0.05$) in fibre tenacity. Of these three cultivars, the cultivar Carmagnola Selezionata gives the best fibre tenacity. Generally, the enzymatic field retted fibres give a slightly better tenacity than the classical field retted fibres.

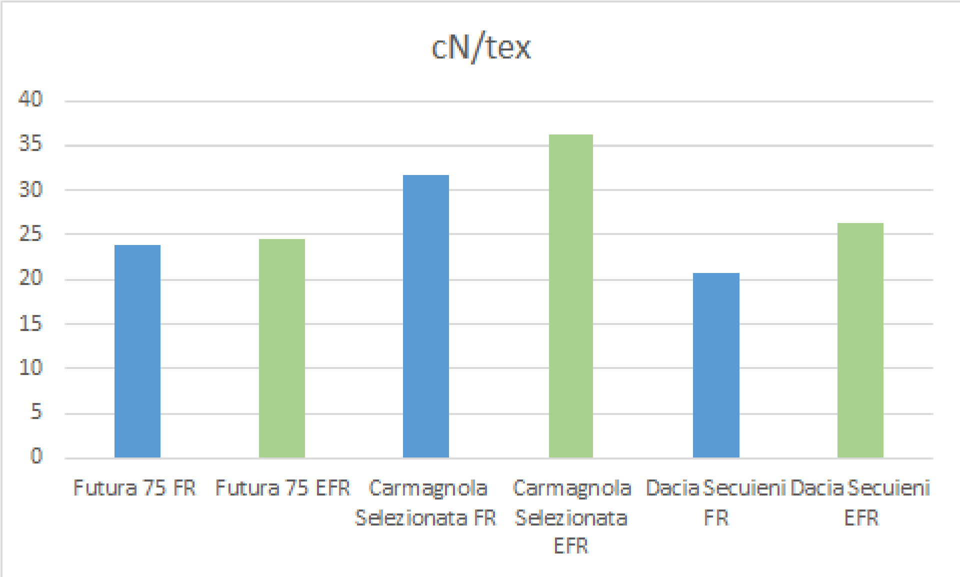

Fig. 2 - Fibre tenacity of Futura 75, Carmagnola Selezionata and Dacia Secuieni after field retting and enzymatic field retting

Conclusion

In this study, genotype proved to be relevant for determining the fibre yield and quality of hemp. Although dry matter yields tended to be higher in the late flowering genotypes (Bialobrzeskie and CS) because they reached a bigger plant height at full flowering (237 cm and 279 cm respectively), bast fibre content was higher in the early flowering genotype (USO 31).

Two types of retting, (dew) field retting and enzymatic field retting with Texazym SER-7 conc., were considered in this paper. The method of retting not only slightly affected the colour but also the fineness and strength of the hemp fibres and the differences were significant depending on the cultivar. Enzymatic field retting seems to be recommended as a better alternative to field retting in terms of fiber tenacity.
The present study confirms that hemp has a great potential for the textile industry as a high yielding fibre crop, but further research on agronomic factors and improvement of the retting process are necessary to ensure a consistent fibre yield, strength and quality.

Acknowledgements

Optimization of hemp fibre quality for textile applications through an integrated chain approach - own grown hemp is a research project that is coordinated by the Department of Fashion, Textile and Wood Technology of the University College Ghent (HOGENT) and which is a collaboration between the Department of Fashion, Textile and Wood Technology and the department Biosciences and Food Sciences of the University College Ghent (HOGENT). The project is financed for three years (2016-2019) by the HOGENT Applied Research Fund (PWO) and involves close collaborations with industrial partners, whose financial and technical support is gratefully acknowledged. It is linked with the Professional Bachelor Programs of Agro-

and Biotechnology and Textile Technology with the aim of strengthening the involvement of students in ongoing research at HOGENT.

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